Observations on Food Preferences, Daily Ration Requirements and Growth of *Haliotis kamtschatkana* Jonas in Captivity

BY

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(4 Text figures)

INTRODUCTION

Haliotis kamtschatkana Jonas, 1845, commonly called the pinto abalone, is found along the outside coastal waters of southeastern Alaska from Dixon Entrance to Icy Straits (Parker, 1973). It is also encountered in British Columbia and occurs as far south as Point Conception, California (Cox, 1962).

The flesh of the pinto abalone has an excellent flavor and is especially tender. Therefore, this animal is eagerly sought by Alaskans for home consumption (Livingstone, 1952). This abalone is commercially harvested on a small scale and recovered meats retailed at approximately $4.- per pound (*ca.* 450 g) in 1975. In Alaska, however, *Haliotis kamtschatkana* is encounterel primarily in patchy aggregations (Livingstone, *op. cit.*); therefore, its fishery potential is probably limited. This is also the case for pinto abalone in British Columbia (Quayle, 1962).

Considering the extensive distribution of *Haliotis kamtschatkana* along the Pacific coast of North America, few papers on the basic biology of the species are available. The most extensive paper is that of Quayle (1971) which primarily provides information on morphometry and estimated growth rates for pinto abalone in British Columbia. A general, but brief, review of distribution and feeding habits can be found in Cox (1962). Livingstone (1952) provides some data on size-weight relations and the percent meat recovery for pinto abalone from the Prince of Wales and Baranof Islands, southeast Alaska. Parker (1973) reported additional information on size-weight relations and determined that sexual maturity in Alaskan *H. kamtschatkana* was reached at a shell length of approximately 65 mm. No published data are available on feeding and growth of the pinto abalone in Alaskan waters.

Recent interest in the southeastern and southcentral Alaskan coastline as aquacultural areas has prompted the examination of the suitability of several native organisms, including *Haliotis kamtschatkana*, for culture. The major purpose of this investigation was to study the feeding and resulting growth of *H. kamtschatkana* in captivity.

METHODS

Collections of 50 and 52 *Haliotis kamtschatkana* were made from Sitka Sound, Alaska, on 14 May and 1 September 1975. The May collection consisted exclusively of sexually mature animals (shell length greater than 65 mm). The September collection contained both sexually immature and mature individuals (shell length of 35 to 100 mm). For the purpose of discussion, the individuals of the May and September collections will be referred to as Collection 1 and Collection 2 respectively. The animals were moved to the Institute of Marine Science, Seward Marine Station at Resurrection Bay, Alaska. There, the abalone were maintained in large fiberglassed plywood tanks. The sea water in which the abalone were kept was pumped from a depth of 73 m to eliminate salinity fluctuations. The salinity of the incoming water ranged from 31 to 33‰. Sea water temperatures were maintained between 12.0 and 15.0° C throughout most of the experiment (Table 1). The experiments were terminated at the end of November 1975 when the heating system no longer maintained the desired temperature (Table 1). The abalone in Collections 1 and 2 were kept in captivity for 200 and 90 days respectively.

The acceptability of 9 species of macroalgae and 2 types of diatoms as food was determined by offering the plant tissues to 25 specimens of *Haliotis kamtschatkana* of various sizes that had been starved for 48 hours. An acceptance of a food item consisted of the abalone grasping the plant tissue with its foot and ingesting at least part of the algae. The diatoms were cultured or settled on glass plates

Table 1

A comparison of sea water temperatures in the experimental tanks to those normally encountered in Sitka where the specimens of *Haliotis kamtschatkana* were originally captured. M.T. = mean temperature, S.D. = standard deviation, R. = range.

Month	M.T.	S.D.	R.	Sitka[1] M.T.
May	9.0	2.60	8-13	8.9
June	13.88	1.20	12-16	11.4
July	15.36	1.48	14-18	13.5
August	14.40	0.89	13-15	14.0
September	14.25	0.88	13-16	12.2
October	12.35	1.26	9-14	9.4
November	7.50	1.79	5-11	7.2

[1]An eleven year average, taken from U.S. Department of Commerce. 1970. Surface water temperature and density. NOS Publication 31-3. p. 30-31.

and these were placed next to the abalone. The algae species tested were those commonly encountered in Resurrection Bay, Alaska, and are not considered an exhaustive list of potential food species. The algal species tested are the following: Diatoms – *Chaetoceros* spp., and *Navicula* spp.; Chlorophyta – *Ulva lactuca* (Linnaeus) and *Enteromorpha linza* (Linnaeus) J. Agardh; Phaeophyta – *Laminaria groenlandica* Rosenvinge, *L. saccharina* (Linnaeus) Lamouroux, *Alaria marginata* Postels & Ruprecht, *Agarum cribosum* Bory, and *Fucus distichus* Powell; Rhodophyta – *Porphyra miniata* (C. Agardh) C. Agardh, and old and new growth *Rhodymenia palmata* (Linnaeus) Greville. Coralline algae were also present as a heavy encrustation on the shells of most of the specimens of *H. kamtschatkana*. Qualitative observations on food preferences were also carried out in tanks where all 11 algae types were present.

The required daily ration of *Haliotis kamtschatkana* was examined by offering known amounts of *Laminaria groenlandica* to various sized abalone. The 6 *H. kamtschatkana* utilized in this experiment were maintained as pairs of animals of similar weights in 220 *l* fiberglassed tanks. These 3 pairs of abalone had average wet weights and shell lengths of 15.8g, 86.3g, 163.8g, and 54mm, 84mm, 104mm respectively. The average daily consumption of *L. groenlandica* for 13 consecutive days was monitored by daily weighing the remaining plant tissue in the tanks to the nearest tenth of a gram. The sea water in the tanks was maintained between 13.5 and 15.0° C.

Growth of abalone, maintained at temperatures similar to those found in their natural habitat (Table 1) during the summer months and fed to excess on *Laminaria groenlandica, Alaria marginata, Chaetoceros* spp. and *Navicula* spp., was monitored by marking the shell margins of each individual with an engraving tool. In addition, their initial length and width was measured to the nearest millimeter and a number ground into each shell. Qualitative weekly observations of growth were made by observing the occurrence of increases in shell length beyond the notch filed in the shell margin. Increases in shell

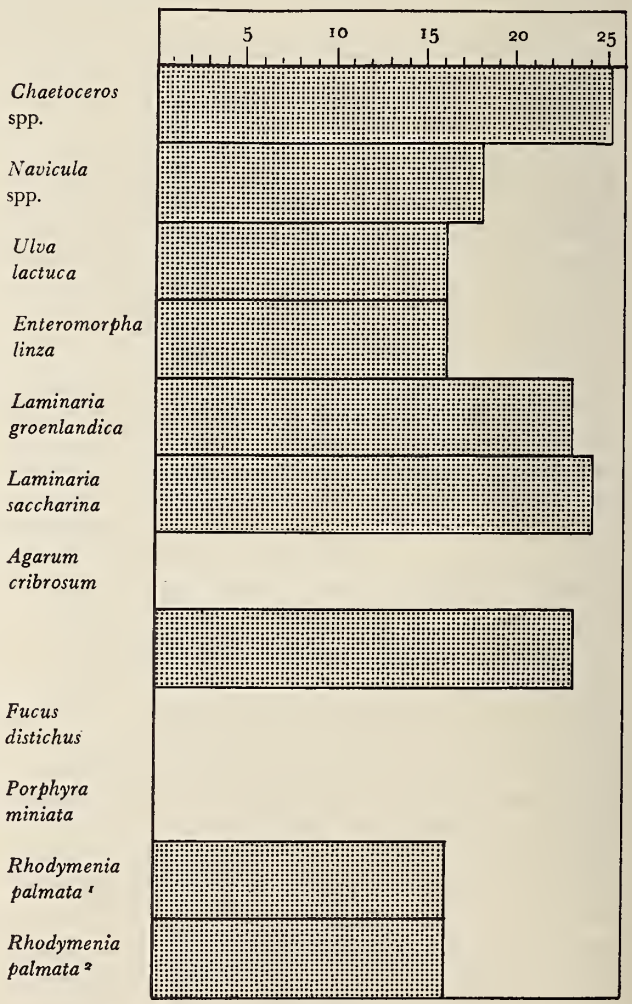

Figure 1

Acceptability of 12 algae types as food to 25 starved *Haliotis kamtschatkana*

[1] new growth tissue; [2] old blade tissue

length were determined to the nearest millimeter at the end of November. The abalone were grouped in 5mm initial length categories and their mean increases in shell length and shell width were determined (Figure 3). A cumulative growth curve for a hypothetical pinto abalone with an initial shell length of 35mm was constructed by adding the mean increase in shell length for the 90 day period reported in Figure 3 for Collection 2 (Figure 4).

RESULTS

FOOD PREFERENCE

The acceptability of 12 types of algae as food to 25 starved *Haliotis kamtschatkana* is presented in Figure 1. Only one plant, the diatom *Chaetoceros* spp., was accepted by all 25 specimens of *H. kamtschatkana* in the food preference study. The other diatom tested, *Navicula* spp., was rejected by 7 individuals.

The green algae *Ulva lactuca* and *Enteromorpha linza* were both accepted by 16 of the 25 abalone tested.

The brown alga, *Laminaria groenlandica*, was rejected by 3 abalone, and *L. saccharina* was rejected by 2 abalone. *Alaria marginata* was accepted by 23 of the 25 individuals tested. *Agarum cribosum* and *Fucus distichus* were both rejected by all 25 *Haliotis kamtschatkana.*

Pieces of newly formed and old *Rhodymenia palmata* blade were both accepted as food by 16 of the abalone tested. *Porphyra miniata* was rejected by all 25 individuals.

DAILY RATION

The average daily consumption of *Laminaria groenlandica* by the 2 smallest *Haliotis kamtschatkana* tested (mean wet weight of 15.8g) was 0.6g per day (Figure 2). Therefore, the average daily intake of plant tissue was 3.7% of their body weight. The intermediate sized abalone (mean wet weight of 86.3g) consumed *L. groenlandica* at an average of 1.8% of their body weight per day or 1.6g per day. The largest individuals examined (mean wet weight of 163.8g) ingested on the average 1.7g of *L. groenlandica* per day or approximately 1% of their body weight per day (Figure 2). The amount of plant tissue consumed on a daily basis fluctuated considerably. This observation is illustrated by the standard deviations and ranges of Figure 2.

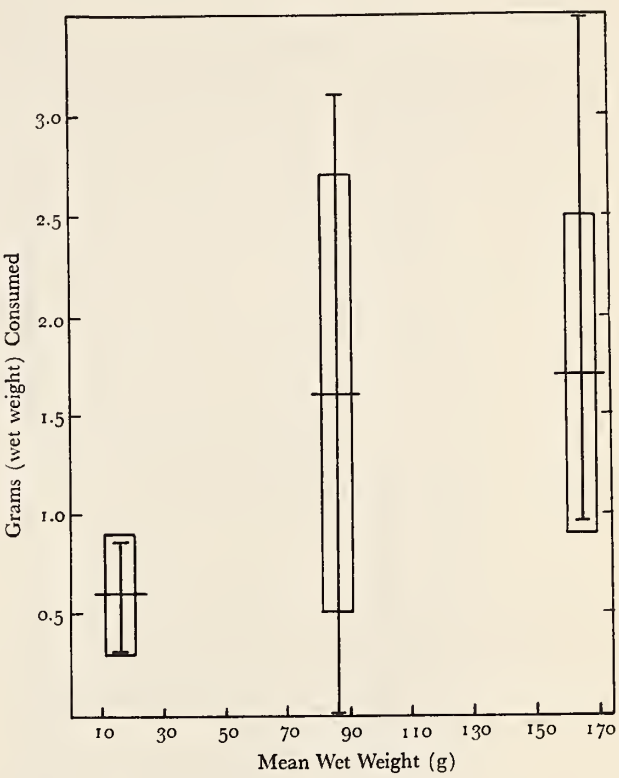

Figure 2

The average daily consumption of *Laminaria groenlandica* by different sizes of *Haliotis kamtschatkana.* Water temperatures: 13.5° C to 15.0° C

GROWTH

As expected, the increase in shell length and width was greatest in the smaller individuals (Figure 3). Specimens in the 35 to 40mm shell length group experienced increases in shell length and width on the order of 10 and 7 mm respectively (Figure 3). Individuals in the 7 size groups from 41 to 75mm (Figure 3) generally increased in length from 4 to 6mm and from 3 to 5mm in width. The individuals in the 2 size groupings (Figure 3) between 76 to 85mm in length increased in length from 2 to 4mm and from 1 to 3mm in width. Individuals from Collection 1 in the 3 size groupings from 91 to 110mm (Figure 3)

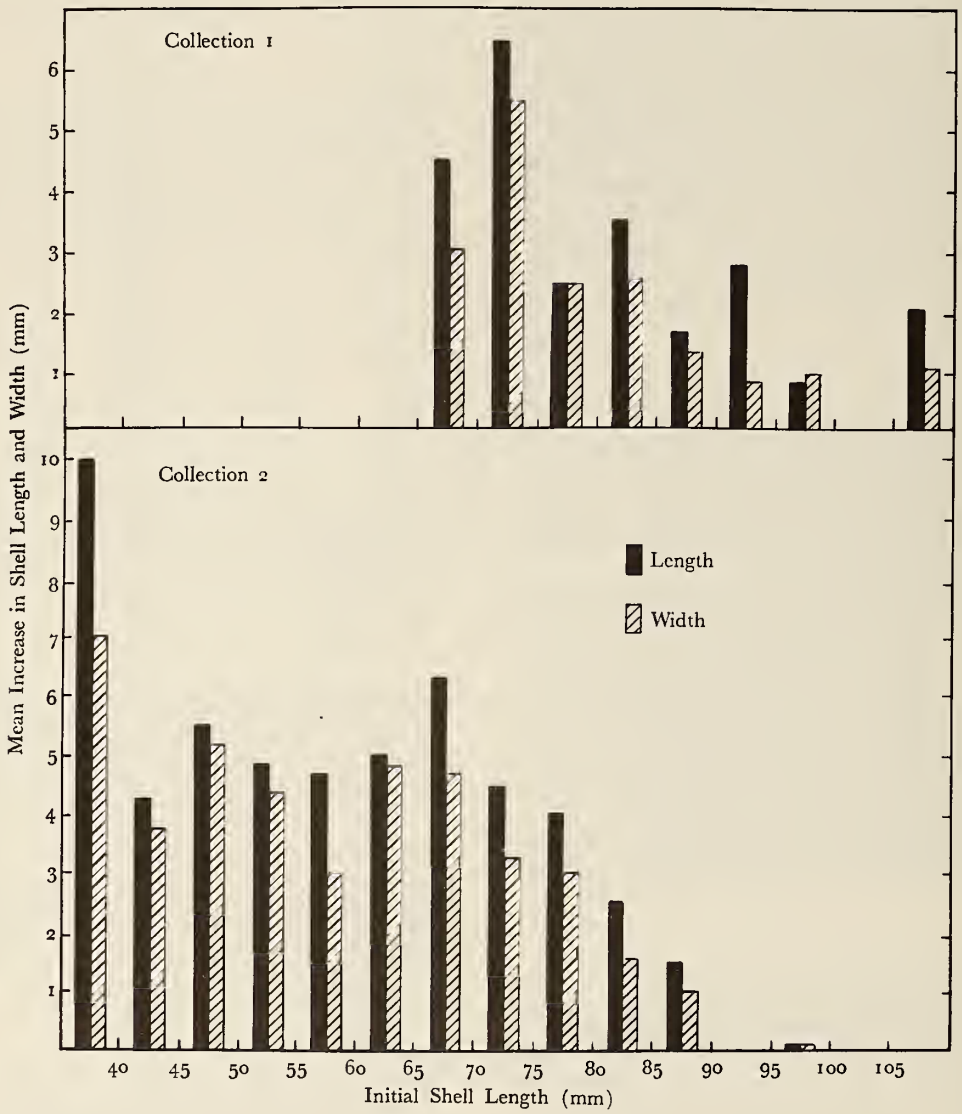

Figure 3

Increases in shell length and width of *Haliotis kamtschatkana* held in captivity for 200 (top) and 90 (bottom) days. Water temperatures: 12.0° C to 15.0° C

showed increases in length of 1 to 3 mm. The specimens in this size range from Collection 2 failed to grow at all (Figure 3). In general, the increase in shell length of the sexually mature individuals in the size groups of 66 to 90 mm in Collections 1 and 2 appears to be similar (Figure 3). Therefore, a one way analysis of variance (see SNEDECOR, 1956) was utilized to compare the differences in increases of shell length of all individuals of these 5 groups (Table 2). No statistical differences at the 99% level of confidence could be observed in the increases of shell length in individuals of the 5 groups compared (Table 2, Figure 3).

Table 2

A comparison (One Way Analysis of Variance) of increase in shell length of two groups of *Haliotis kamtschatkana* held for 200 and 90 days respectively. S.L. = shell length (mm). D.F. = degrees of freedom. M.S. = mean square. F. = F ratio

Treatment Group (S.L.)	Source of Variation	D.F.	M.S.	F =	Significant Difference (99% level)
66-70	sample means	1	4.96		
	individuals	6	1.41	3.5	No
71-75	sample means	1	6.81		
	individuals	8	6.27	1.08	No
76-80	sample means	1	7.03		
	individuals	6	6.32	1.11	No
81-85	sample means	1	1.64		
	individuals	9	2.11	0.77	No
86-90	sample means	1	0.01		
	individuals	3	0.89	0.01	No

DISCUSSION

FOOD PREFERENCE

No previous detailed work is available concerning the food preference of *Haliotis kamtschatkana*. Cox (1962) makes the statement that this species typically ingests small algae; species unidentified but non-diatomaceous, (Cox, personal communication 1976) in preference to the larger types, such as *Laminaria*, which is popular with other species of abalone. In the current observations of feeding *H. kamtschatkana*, diatoms, *Chaetoceros* spp. and *Navicula* spp., were among the preferred food items. Whenever a visible film of these diatoms coated the sides and bottoms of the aquaria, pinto abalone actively grazed on it, ignoring the macroalgae. However, in the absence of a diatom film, there was a decided preference for the brown algae *Laminaria saccharina*, *L. groenlandica*, and *Alaria marginata*.

Ino (1953) and Leighton (1959) discuss the importance of benthic diatoms and coralline algae to abalone during metamorphosis from the early creeping stages to the adult form. However, most North American species of *Haliotis* generally adopt a diet of macroalgae as they increase in size. Cox (1962) speculated that the diet of adult *H. kamtschatkana* contains greater amounts of coralline and diatomaceous algae than do the diets of other species of California abalone. Cox based this theory on the mottling of the shell color in pinto abalone which is characteristic of this type of diet. The results of the current food preference studies on pinto abalone support this theory. In addition to a decided preference for diatoms over macroalgae, individual pinto abalone were often observed feeding on the coralline algae encrusting the shells of other abalone.

DAILY RATION

No data exist concerning the relative value of different species of algae for growth in *Haliotis kamtschatkana*. Kikuchi *et al.* (1967) carried out rearing experiments on *Haliotis discus hannai* Ino, 1952 fed 20 kinds of marine algae. They reported maximum growth in shell length and increase in weight with the brown algae *Undaria* and *Eisenia*.

Within the 3 size groups, the daily intake of plant tissue by *Haliotis kamtschatkana* exhibited fairly wide ranges and large standard deviations (Figure 2). Therefore, to insure maximum growth of pinto abalone in captivity, daily rations must be calculated at the highest possible level of daily consumption. Daily consumption levels of 0.8, 3.1, and 3.5 g of *Laminaria groenlandica* were the maximums observed in the 3 size groupings of *H. kamtschatkana* examined (Figure 2). These values represent 5%, 3% and 2% of the average body weight of the abalone in the 3 test groups.

GROWTH

The failure of the specimens collected in May to exceed the growth of those introduced into the tanks in September, in spite of the fact that they were held for an

additional 110 days, can be explained by the ripening of the gonads of the first collection while in captivity. Weekly observations of increases in shell length indicated negligible growth during the period of mid-May to mid-August. However, during this period the gonads of the specimens in Collection 1 ripened and several individuals spawned. The first spawning was recorded on 10 June 1975, the water temperature was 9° C. Individuals continued to spawn intermittently until 4 July 1975. During this period of spawning activity, increases in shell length were negligible. New growth first appeared at the shell margins of those individuals during mid-August. The sexually mature individuals in Collection 2 did not spawn while in captivity; they had already completed their spawning in the wild by late August. Since the growth of the 2 groups was similar, it is reasonable to assume the gonadal maturation interfered with shell growth in Collection 1 during late spring and early summer. However, the specimens with initial shell lengths larger than 90 mm from Collection 1 did grow, while those from Collection 2 did not.

The growth measurements indicate the growth of the sexually immature (35 - 65 mm shell length) and just maturing (66 - 75 mm shell length) individuals occurs at a relatively rapid rate (Figure 3) with increases in shell length of 5 - 10 mm during the 90 days of observed growth. As expected, the sexually mature animals grew at a slower rate. The construction of a cumulative growth curve (Figure 4), based on adding the increments in size observed in Figure 3, Collection 2, indicates that it would be possible for an individual to grow from 35 mm to sexual maturity in 450 days if fed to repletion and maintained between 12 and 15° C (Figure 4). Currently, there are no data on the actual age of *Haliotis kamtschatkana* at a shell length of 35 mm in Alaskan waters. Quayle (1971) estimated that 2 years are required for *H. kamtschatkana* to reach this size in British Columbia, Canada. However, the Japanese are able to raise *H. discus hannai*, once considered a Japanese race of *H. kamtschatkana*, to 35 mm in one year under controlled conditions (Sakai, 1962).

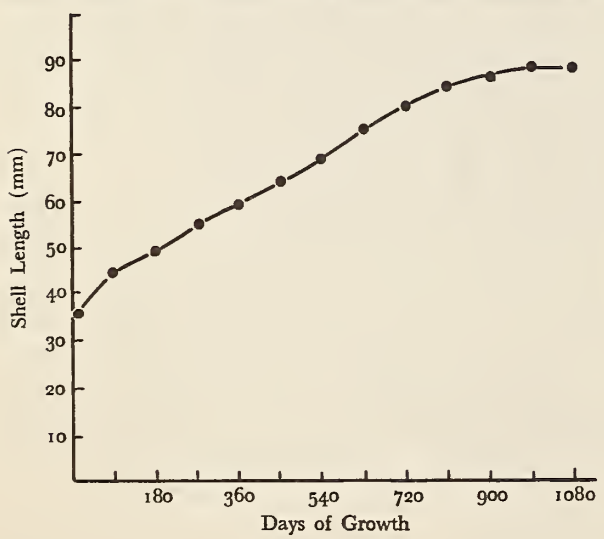

Figure 4

A cumulative growth curve for *Haliotis kamtschatkana* held in captivity and fed to repletion.
Water temperatures: 12.0° C to 15.0° C

Quayle (1971), following the growth of marked *Haliotis kamtschatkana*, determined that approximately 3.5 years are required for *H. kamtschatkana* to grow from 35 to 75 mm shell length off the coast of British Columbia as compared to the 1.6 years indicated by the cumulative growth curve (Figure 4). Therefore, the effect of the maintenance of summer temperature and an abundance of food on the growth rate of *H. kamtschatkana* is clearly demonstrated.

The results of these experiments indicate that *Haliotis kamtschatkana* will grow in captivity and can be fed commonly occurring species of algae. However, further work on the early life stages, growth in the wild, nutrition, and availability of heated sea water are required to properly assess the role of *H. kamtschatkana* in Alaskan aquaculture.

SUMMARY

1. *Haliotis kamtschatkana* exhibited a decided preference for the diatoms *Chaetoceros* spp. and *Navicula* spp. as food.

2. The following algae were also acceptable food items:
Chlorophyta – *Ulva lactuca* and *Enteromorpha linza*;
Phaeophyta – *Laminaria groenlandica*, *L. saccharina*, and *Alaria marginata*;
Rhodophyta – *Rhodymenia palmata*

3. The following algae were not acceptable food items:
Phaeophyta – *Agarum cribosum*, and *Fucus distichus*;
Rhodophyta – *Porphyra miniata*.

4. The maximum daily consumption of *Laminaria groenlandica* for pinto abalone with a body weight of 15 g, 86 g, and 164 g was 5%, 3%, and 2% of their body weights per day respectively.

5. The increase in shell length of 2 collections of pinto abalone held for 200 and 90 days and fed to excess on *Laminaria groenlandica*, *Alaria marginata* and the

diatoms *Chaetoceros* spp. and *Navicula* spp. is presented. A cumulative growth curve is also presented.

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Literature Cited

Cox, Keith W.
1962. California abalones, family Haliotidae. Fish. Bull. 118; Calif. Dept. Fish and Game, Sacramento, Calif.; 133 pp.

Ino, Takashi
1952. Biological studies on propagation of Japanese abalone. Bull. Tokai Region. Fish. Res. Labor. No. 5: 1 - 102

Kikuchi, Syogo, Yasuo Sakurai, Minoru Sasaki & Tomio Ito
1967. Food values of certain marine algae for the growth of the young abalone, *Haliotis discus hannai*. Bull. Tohoku Region. Fish. Res. Labor. 244: 93 - 100

Leighton, David L.
1959. Diet and its relation to growth in the black abalone, *Haliotis cracherodii*. Univ. Calif. at Los Angeles, Master's Thesis, 61 pp.

Livingstone, Robert, Jr.
1952. Preliminary investigation of the southeastern Alaska abalone *(Haliotis kamtschatkana)*. Commerc. Fish. Rev. 14 (9): 8 - 18

Parker, James W.
1973. The abalone in Alaska. Alaska Dept. Fish & Game Wildlife Notebook Series, 2 pp.

Quayle, Daniel Branch
1962. Abalones in British Columbia. Progr. Rprt. Pacif. Coast Stations Fish. Res. Brd. Canada No. 114: 9 - 12
1971. Growth, morphometry and breeding in the British Columbia abalone (*Halotis kamtschatkana* Jonas). Fish. Res. Brd. Canada, Tech. Rprt. No. 279: 84 pp.

Sakai, Seiichi
1962. Ecological studies on the abalone, *Haliotis discus hannai* Ino — IV. Studies on the growth. Bull. Japan. Soc. Scient. Fish. 28 (9): 899 - 904

Snedecor, George W.
1956. Statistical methods applied to experiments in agriculture and biology. 5th ed. Iowa State Coll. Press, Ames, 534 pp.